MACHINING SINTER HARDENABLE P/M MATERIALS

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Sinter hardening enables P/M parts to reach high apparent hardness in the as-sintered condition without post-sintering heat treatment, avoiding thermal stresses and distortion usually associated with quenching. However, because sinter hardened parts exhibit high apparent hardness, they are difficult to machine. For those components requiring a machining operation, it is possible to perform a pre-sintering treatment to increase the interparticle bonding strength while avoiding the formation of martensite in the ferrous matrix. A test program has been carried out to evaluate the effect of the pre-sintering temperature on the strength and machinability of a water-atomized steel powder specifically designed for sinter hardening applications. The Cr-Mn-Ni-Mo prealloyed powder was admixed with 2% copper and 0.9% graphite. Specimens were pre-sintered at temperatures ranging from 650 to 970°C. Transverse rupture strength measurements, machinability tests and microstructural characterization were performed on pre-sintered specimens to define the optimum processing conditions. The transverse rupture strength, apparent hardness, drilling thrust force and torque increased with the pre-sintering temperature. Pre-sintering in the range of 810 to 890°C was found to assure a good combination of machinability and particle bonding.

INTRODUCTION: Sinter hardening is an attractive technique to produce high strength and high apparent hardness P/M parts at a lower cost than the conventional quench and temper process. The development of a new low alloy steel powder enables P/M parts to sinter harden in conventional sintering furnaces [1,2]. However, sinter hardened parts are difficult to machine because of their high hardness. Previous work carried out on P/M materials has shown that unalloyed steels machine better than low alloy steels and that 0.5% carbon steels machined better than those containing 0.8% carbon [3]. In this study, materials exhibiting high hardness generally showed poor machinability and the use of machinability enhancers such as MnS improved their machining behavior. In another study, it was demonstrated that the sintering time significantly affects the apparent hardness and strength of a P/M material and hence, its machinability [4]. Green machining could also be an alternative but green strength must be high enough to allow efficient clamping [5].

By carrying out an appropriate heat treatment on a green part, the strength of the parts can be raised to a level sufficient to assure adequate machining. The objective of this study is to evaluate the effect of the pre-sintering temperature on the drilling thrust force and torque measured when drilling holes in specimens made of a material designed to sinter harden and to study how the strength and apparent hardness affect the machinability of these materials.

EXPERIMENTAL PROCEDURES: ATOMET 4701, an atomized steel powder prealloyed with 0.45% Mn, 0.45% Cr, 0.90% Ni and 1.0% Mo, was used as base material. Specimens were pressed to a green density of 6.8 g/cm^3 from a mix containing 0.90% graphite, 2.0% copper and 0.75% EBS wax. They consisted of standard TRS specimens, 3.18 cm in length, 1.27 cm in width and 0.64 cm in thickness for strength measurements, and 1.27 cm thick specimens for machinability evaluation. Five pre-sintering temperatures, 650, 730, 810, 890 and 970°C, were used for this study. The time at temperature was 28 minutes in a nitrogen based atmosphere containing 10% hydrogen. Cooling rate from the pre-sintering temperature was about 1°C/s. The machinability set-up used to measure the drilling thrust force and torque is illustrated in Figure 1. It consisted of a high power press drill with automatic feed rate control equipped with a specimen holder capable of monitoring the torque applied on the tool and the thrust force transmitted to the test component. The acquisition system enables the measurement of the feed rate, rotating speed, thrust force and torque nine times per second. Data are transmitted to a computer for processing. The procedure used to analyze and qualify the drills prior to testing is described elsewhere [6]. The cutting tools used for this study were black oxide coated high speed steel drills with a helix angle of 118° and a diameter of 6.35 mm. The cutting speed and feed rate were respectively 2220 RPM and 0.12 mm/rev. Fifteen holes were drilled to a depth of 1.12 cm for each test condition.

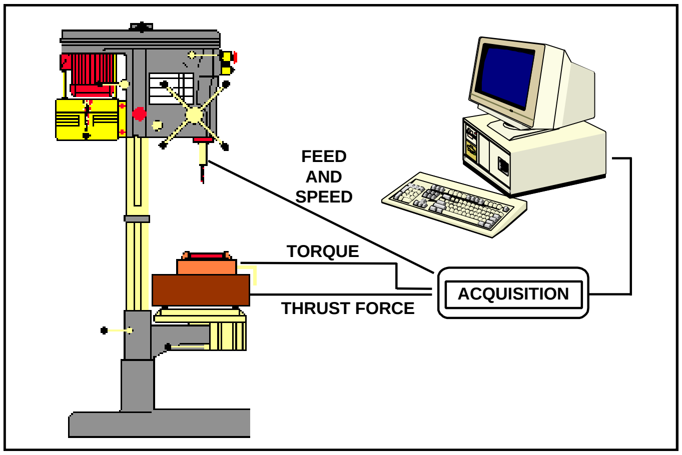

Figure 1. Set-up Used to Evaluate Drilling Thrust Force and Torque.

RESULTS AND DISCUSSION: Figure 2 illustrates the evolution of the drilling thrust force and torque when drilling holes in specimens pre-sintered at 650, 730, 810, 890 and 970°C. The thrust force and torque increase with pre-sintering temperature and the drill failed at the first hole when drilling in the material pre-sintered at 970°C. Also, both the thrust force and the torque slightly increase with the number of holes. This is caused by the wear of the drill cutting edge. Finally, the slope of the thrust force curves is similar for all materials except that of the torque curve at 890°C which is slightly steeper than for the other temperatures. This could be an indication that the chips are more difficult to form and expel from the drilled cavity.

Figure 3 illustrates the effect of the pre-sintering temperature on the average thrust force and torque measured while drilling the 15 holes for the materials pre-sintered in the temperature range of 650 to 890°C and for the only one drilled at 970°C. The thrust force increases linearly in the range of 650 and 890°C. Beyond this temperature, a sharp increase of the thrust force is observed. For the torque, the rate of increase with temperature is almost linear for the range of temperatures studied.

Figure 4 illustrates the relationship between the transverse rupture strength (TRS) and the average thrust force and torque (Figure 4a) and between the apparent hardness and the average thrust force and torque (Figure 4b). The thrust force sharply increases from 300 to 380 N as the TRS increases from 70 to 150 MPa. A further increase of TRS from 150 to 320 MPa is accompanied by a slower increase of the thrust force from 380 to 430 N. Finally, as the TRS increases from 430 to 720 MPa, the rate of increase of the thrust force again sharply augments from 430 to 610 N, where the drill failure occurs. The torque curve shows a trend similar to that of the thrust force but a reduction of the rate of increase is observed at about 1 joule and a TRS value of 320 MPa. Both the thrust force and torque show similar relationships with apparent hardness: below 50 HRB, the rates of increase of the thrust force and torque are slow but rise sharply between 50 and 90 HRB at which the drill failed.

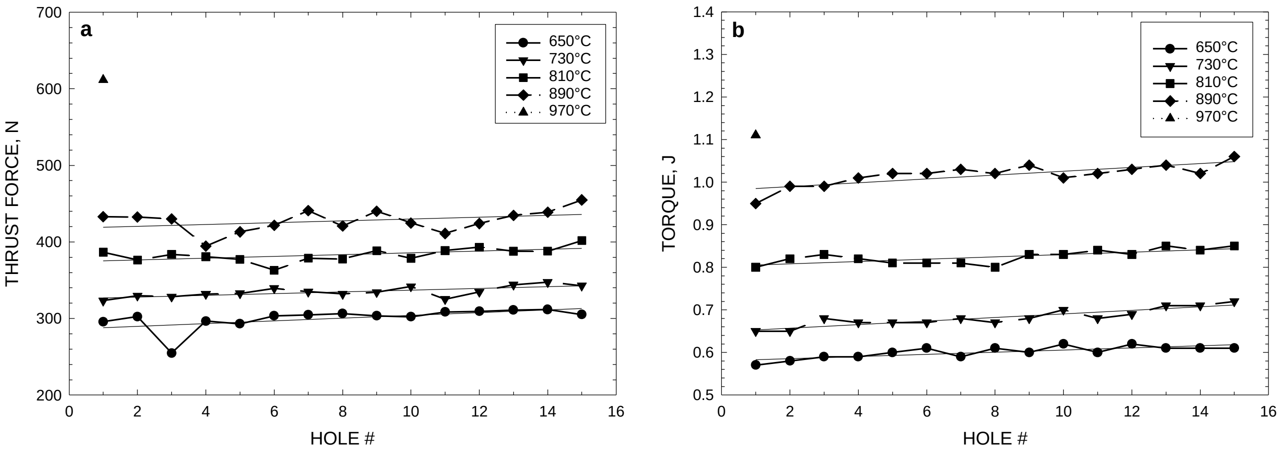

Figure 2. Average Thrust Force (a) and Torque (b) Measurements When drilling Holes in Specimens Pre-Sintered at 650, 730, 810, 890 and 970°C.

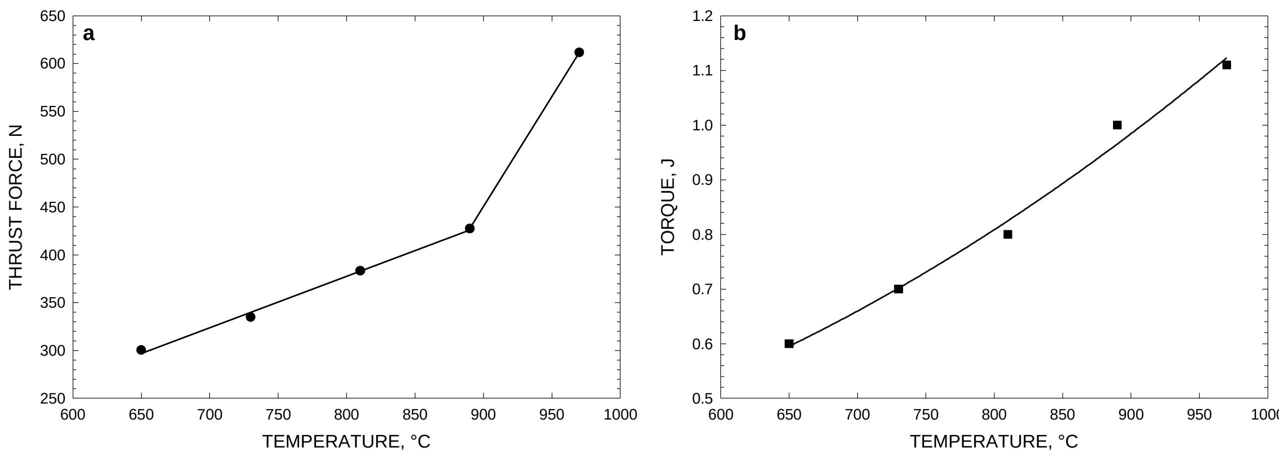

Figure 3. Effect of Pre-Sintering Temperature on Average Thrust Force (a) and Torque (b).

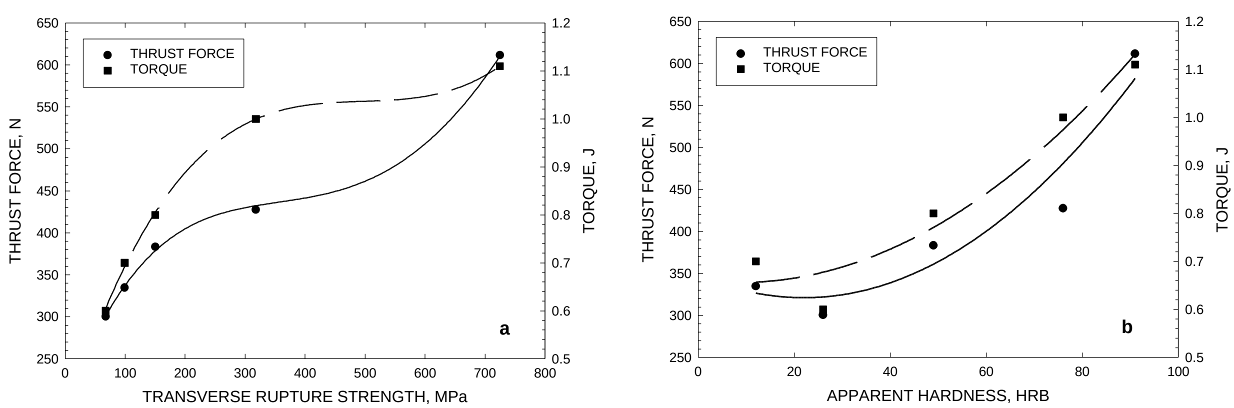

Figure 4. Relationship Between Transverse Rupture Strength (a) and Apparent Hardness (b) with the Average Thrust Force and Torque Required to Drill 15 Holes.

Figure 5 illustrates the microstructures obtained at the various pre-sintering temperatures. It is seen that the diffusion of graphite begins at about 730°C and is not yet completed at 810°C. At 890°C, the microstructure is composed of fine pearlite, while at 970°C, in addition to the fine pearlite, there are many areas of bainite and martensite. Also, undissolved copper can be seen in the matrix because the pre-sintering temperature was below its melting point (1085°C). Finally, there is no evidence of bonding between the steel particles at 650 and 730°C but becomes more evident at 890°C. The stronger metallurgical bonds between the steel particles in addition to the presence of hard constituents such as bainite and martensite could explain the poor machinability of the specimens pre-sintered at 970°C.

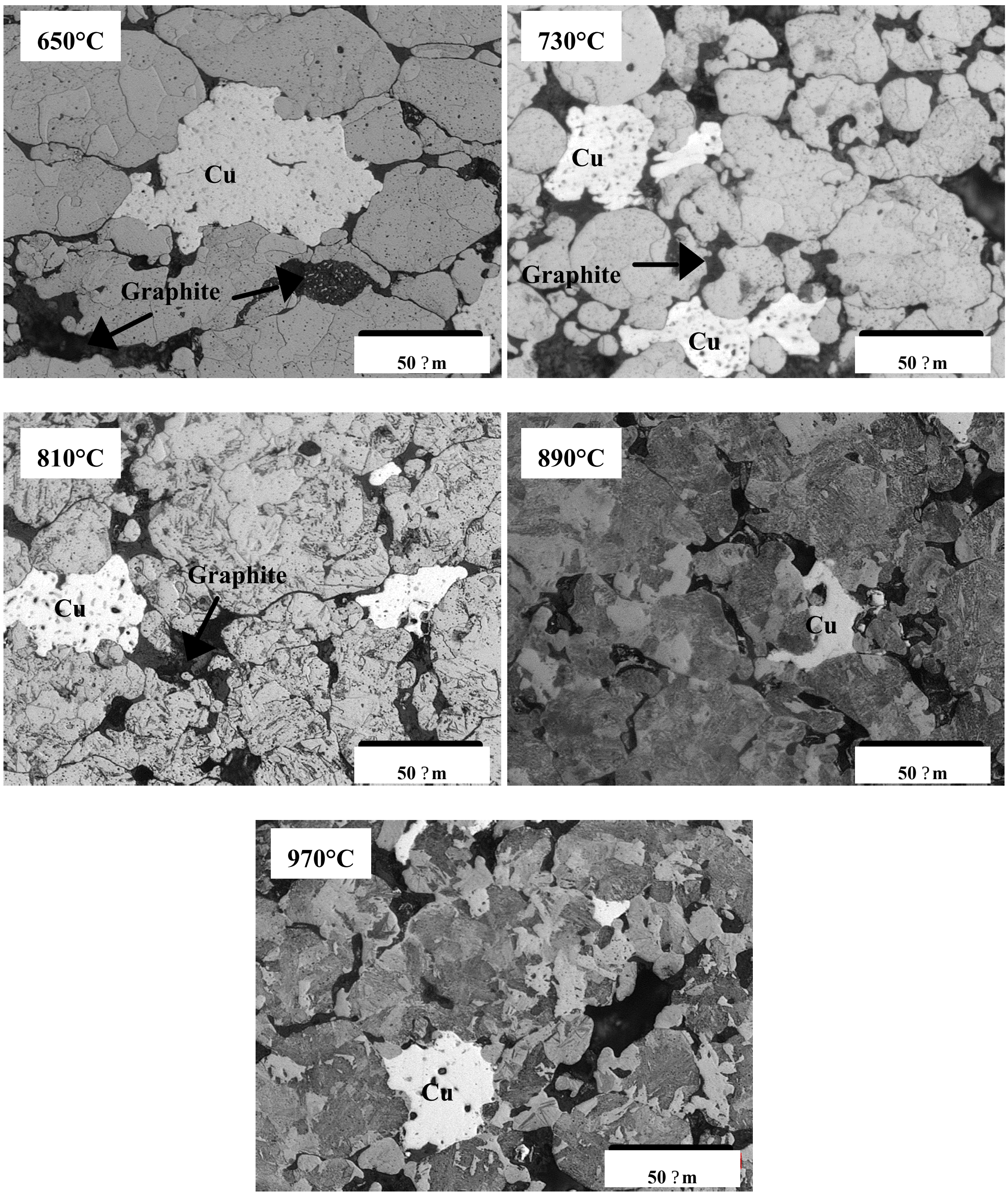

Figure 5. Microstructures of Specimens Made from ATOMET 4701 with 0.9% Graphite, 2% Cu at 6.8 g/cm^3 After Pre-Sintering Treatments.

As illustrated in Figure 6, the nature of the layer under the drilled surface varies with the pre-sintering temperature. At 650°C, the soft ferritic grains are deformed but the weak interparticle bonding minimizes the thickness of the densified layer because the material is easily removed as the drill penetrates into the specimen. At 810°C, the pearlitic grains

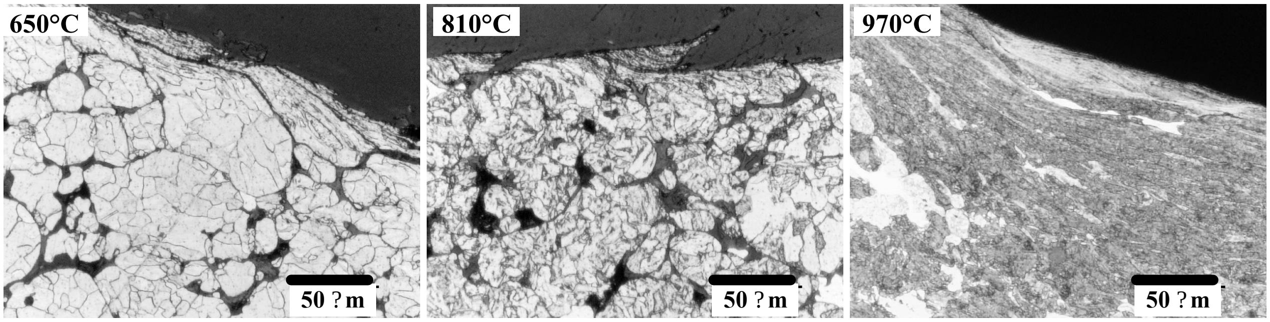

Figure 6. Surface Under the Cut of Specimens Made from ATOMET 4701 with 0.9% Graphite, 2% Cu at 6.8 g/cm³ for Pre-Sintering Temperatures of 650, 810 and 970°C.

sufficiently increase the strength and hardness to minimize the densification under the surface of the cut. This results in a more uniform surface finish in the drilled cavity. At 970°C, the difficulty to form and expel the chips results in a large densification of the layer under the surface of the cut due to the constant penetration of the drill. This explains the high values of thrust force and torque measured with this specimen and the failure of the drill after only one hole.

Figure 7 shows the wear land developed on the edge of the drills used to machine the pre-sintered specimens. At 650 and 730°C, the wear developed on the drill edge is larger than at 810 and 890°C. This is probably caused by the lower strength and hardness of these specimens which favor the densification of the layer below the surface of the cut. On the other hand, at 970°C, the high strength and hardness of the material due to the presence of bainite and martensite rapidly deteriorate the cutting edge of the tool. Hence, the optimum temperature that would assure good machinability

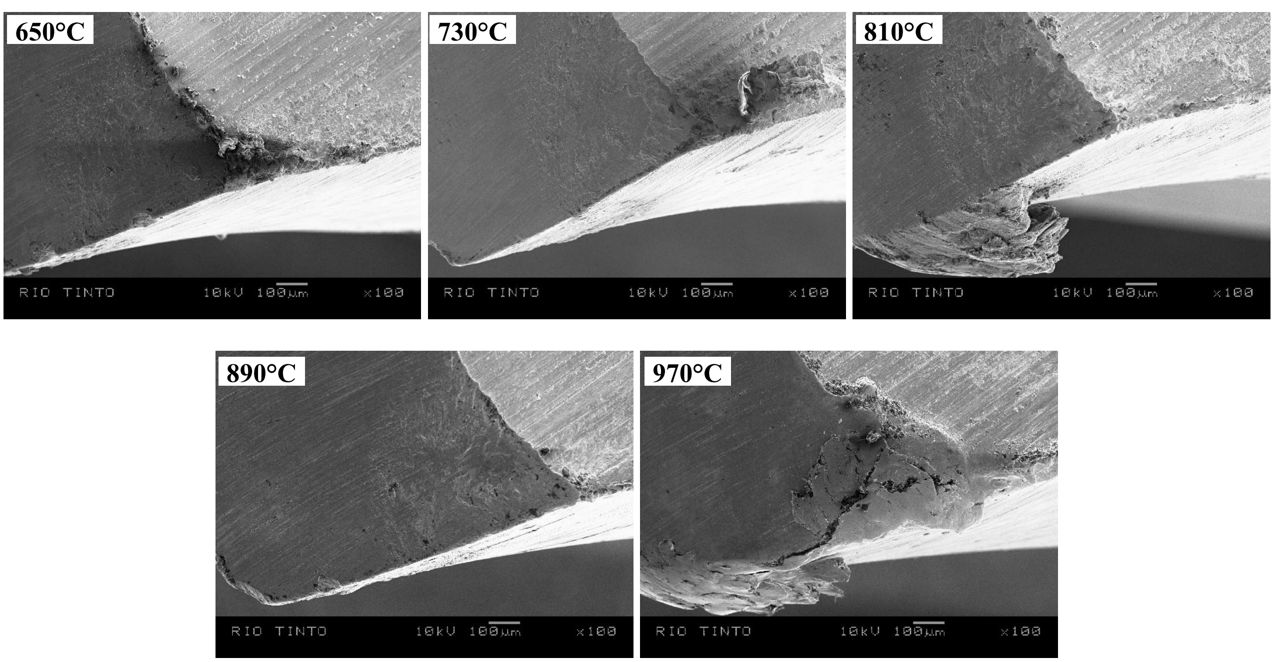

Figure 7. Tool Wear Developed on the Drills for the Specimens Made from ATOMET 4701 with 0.9% Graphite, 2% Cu at 6.8 g/cm³ at Various Pre-Sintering Temperatures.

and hole integrity would be above 810°C to get some pearlite in the specimens but probably below 890°C where the microstructure is fully pearlitic. This corresponds to TRS and apparent hardness values in the range of 150 to 320 MPa and 49 to 76 HRB respectively, with a pearlitic microstructure.

CONCLUSIONS

1. Drilling thrust force and torque when drilling pre-sintered specimens increase with the pre-sintering temperature. For thrust force, the rate of increase is linear in the temperature range of 650 to 890°C while for torque, it is almost linear in throughout the range of temperatures studied. This was related to an increase of the mechanical strength and hardness of the material due to the formation of metallurgical bonds between the steel particles and the diffusion of graphite into the ferrous matrix.

2. The optimum pre-sintering temperature for drilling was found to be in the range of 810 to 890°C. At 650 and 730°C, the presence of soft ferritic grains promotes the densification of the layer under the surface of the cut as the drill penetrates the material. The diffusion of graphite and the metallurgical bonds formed between particles for pre-sintering temperatures ranging from 810 to 890°C minimize the densification of the layer under the surface of the cut. At 970°C, the presence of hard martensite and bainite rapidly leads to the destruction of the cutting edge of the tool.

3. The optimum microstructure which enables a smooth cutting surface of the drilled cavity is composed of pearlite. This corresponds to TRS and apparent hardness values ranging from 150 to 320 MPa and 49 to 76 HRB respectively.

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